RECENT RESULTS FROM CLEO-c

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Abstract

This paper describes recent preliminary results from the CLEO-c experiment using an initial ~ 60 pb^{-1} sample of data collected in e^+e^- collisions at a center of mass energy around the mass of the $\psi(3770)$. A first measurement of the branching fraction $\mathcal{B}(D^+ \to \mu^+\nu) = (3.5 \pm 1.4 \pm 0.6) \times 10^{-4}$ and the corresponding decay constant $f_D = (202 \pm 41 \pm 17)$ MeV has been made. Several charged and neutral D meson absolute exclusive semileptonic branching fractions have been measured, including first measurements of the branching fractions $\mathcal{B}(D^0 \to \rho^- e^+\nu) = (0.19 \pm 0.04 \pm 0.02)\%$ and $\mathcal{B}(D^+ \to \omega e^+\nu) = (0.17 \pm 0.006 \pm 0.01)\%$. Estimated uncertainties for inclusive D semileptonic decay modes are also presented. Fits to single and double D tagged events are used to extract absolute branching fractions of several hadronic D decay modes and $D\overline{D}$ production cross sections. Most of these results from this small preliminary sample are already of greater sensitivity than previously published results.

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1 Introduction

The CLEO-c physics program is focused on the study of charm decays in e^+e^- collisions in the CESR-c storage ring at energies near the $\psi(3770)$ and J/ψ resonances and above $D_s\overline{D_s}$ threshold. The results presented in this paper are based on approximately 60 pb^{-1} of data collected at the $\psi(3770)$, just above $D\overline{D}$ threshold.

For many electroweak quantities measured by the B factories at SLAC and KEK, in particular many that contribute to constraining the CKM unitarity triangle [1], the precision is limited by theoretical uncertainties rather than experimental precision. One of the primary goals of these measurements is the calibration and validation of lattice QCD. Lattice QCD will soon be able to predict many quantities such as the decay constants f_D and f_{D_S} of D and D_S mesons with few percent uncertainties. Measurement of f_D will lead to a determination of f_B, since lattice QCD can predict the ratio f_B/f_D better than the absolute decay constants. It is critical, however, that the uncertainties of the lattice calculations be verified by experimental measurements. CLEO-c measurements of absolute branching fractions and form factors for a full isospin set of semileptonic decays will provide a stringent test of form factor calculations and models.

In addition to verification of lattice QCD, CLEO-c will improve on the existing measurements of $|V_{cs}|$ and $|V_{cd}|$ and measure absolute branching fractions for many important hadronic normalization modes which contribute significant uncertainties to important measurements at higher energies.

2 Purely Leptonic D Meson Decay Absolute Branching Fraction and the Decay Constant f_D

The decay constant f_D is an important parameter which quantifies the annihilation probability of the valence quarks of the D meson. This parameter can be determined from the absolute branching fraction $\mathcal{B}(D^+ \rightarrow \mu^+\nu)$. A first measurement of the absolute branching fraction of the decay $D^+ \rightarrow \mu^+\nu$ was recently made by CLEO-c.

The analysis relies on fully reconstructing or "tagging" one D or $\overline{D}$ meson in the $D\overline{D}$ pair produced in the $\psi(3770)$ decay. This technique works quite well at the $\psi(3770)$ resonance, since there is not enough energy in the event to produce hadrons other than the $D\overline{D}$ pair. Using the decay modes $D^- \rightarrow K^+\pi^-\pi^-$, $K^+\pi^-\pi^-\pi^0$, $\overline{K^0_S}\pi^-$, $\overline{K^0_S}\pi^-\pi^-\pi^+$, $\overline{K^0_S}\pi^-\pi^0$ for the tag side D, an efficiency of approximately 25% for the tag reconstruction is achieved.

A very pure sample of 28651 ± 207 tagged D mesons is selected. The tag D meson is combined with an additional charged track of the correct sign, presumed to be a muon. The distribution of "missing mass squared", defined to

be $M^2_{\mathrm{miss}} \equiv (E_{\mathrm{beam}} - E_{\mu^+})^2 - (\vec{p}_{D^-} - \vec{p}_{\mu^+})^2$, is shown in Fig. 1. A significant and well-defined peak of eight events at the neutrino mass around zero is observed. The peak at 0.25 GeV$^2/c^4$ corresponds to a background from decays to the $K^0_L \pi^+$ final state, which is well separated from the signal region. The total contribution of backgrounds in the signal region is estimated in a maximum likelihood fit to be one event. This leads to a branching fraction of $\mathcal{B}(D^+ \to \mu^+ \nu) = (3.5 \pm 1.4 \pm 0.6) \times 10^{-4}$ and a D meson decay constant of $f_D = (202 \pm 41 \pm 17)$ MeV, where the first uncertainty is statistical and the second is systematic [2].
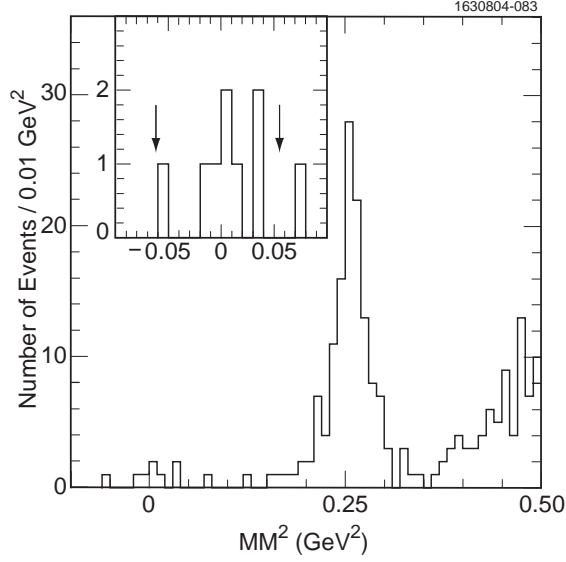

Figure 1: *Missing mass distribution of $D^+ \to \mu^+ \nu$ candidates. The signal peaks at zero missing mass.*

3 Absolute Branching Fractions of Exclusive Semileptonic D Meson Decays

The analysis of exclusive semileptonic decays also uses a tag of the other D meson in the event. These tag D mesons are selected using the beam-constrained mass of the candidate, defined as

$$M_{bc} \equiv \sqrt{E^2_{\mathrm{beam}} - \vec{p}^{\,2}_{\mathrm{cand}}}, \tag{1}$$

Table 1: *Absolute branching fraction measurements by CLEO-c (center column) compared with the present measurements tabulated in the particle data book [3] (right). All results are preliminary.*

Decay Mode	B (%) (CLEO-c)	B (%) (PDG '04)
$D^0 \to \pi^- e^+ \nu$	$0.25 \pm 0.03 \pm 0.02$	0.36 ± 0.06
$D^0 \to K^- e^+ \nu$	$3.52 \pm 0.10 \pm 0.25$	3.58 ± 0.18
$D^0 \to K^{*-}(K^-\pi^0)e^+\nu$	$2.07 \pm 0.23 \pm 0.18$	2.15 ± 0.35
$D^0 \to \rho^- e^+ \nu$	$0.19 \pm 0.04 \pm 0.02$	$-$
$D^+ \to \overline{K}^0 e^+ \nu$	$8.71 \pm 0.38 \pm 0.37$	6.7 ± 0.9
$D^+ \to K^{*0}(K^-\pi^+)e^+\nu$	$5.70 \pm 0.28 \pm 0.25$	5.5 ± 0.7
$D^+ \to \pi^0 e^+ \nu$	$0.44 \pm 0.06 \pm 0.03$	0.31 ± 0.15
$D^+ \to \rho^0(\pi^+\pi^-)e^+\nu$	$0.21 \pm 0.04 \pm 0.02$	0.25 ± 0.10
$D^+ \to \omega(\pi^+\pi^-\pi^0)e^+\nu$	$0.17 \pm 0.06 \pm 0.01$	$-$

and the energy difference between the beam and the candidate, defined to be

$$\Delta E = E_{\text{beam}} - E_{\text{cand}}. \qquad (2)$$

The remaining observable tracks are then reconstructed to form the daughter meson. The missing energy, E_{miss}, and missing momentum, $|\vec{p}_{\text{miss}}|$, in the event are used to form the kinematic variable $U \equiv E_{\text{miss}} - |\vec{p}_{\text{miss}}|$, which is fit to determine the signal and background contributions. These distributions and fits are shown in Fig. 2 and Fig. 3 for the neutral and charged D meson modes, respectively.

These raw numbers of events are corrected for efficiency and divided by the number of tag D mesons to produce absolute branching fractions. The efficiencies are determined using a combination of GEANT Monte Carlo and data. These measurements include first observations of the modes $D^0 \to \rho^- e^+ \nu$ and $D^+ \to \omega e^+ \nu$.

The absolute branching fraction measurements for these modes are summarized in Table 1. Even with only a small fraction of the final sample, the sensitivity is already an improvement over previous measurements [3] for most modes.

4   Inclusive Decay Channels

The inclusive branching fractions $\mathcal{B}(D^0 \to e^+ X)$ and $\mathcal{B}(D^+ \to e^+ X)$ are being measured by the CLEO-c collaboration. At present, the branching fractions are not yet public, however, even with the preliminary ~ 60 pb^{-1} sample, the statistical uncertainties are $\sim 0.2\%$ and $\sim 0.3\%$ for the $D^0 \to e^+ X$ and $D^+ \to e^+ X$
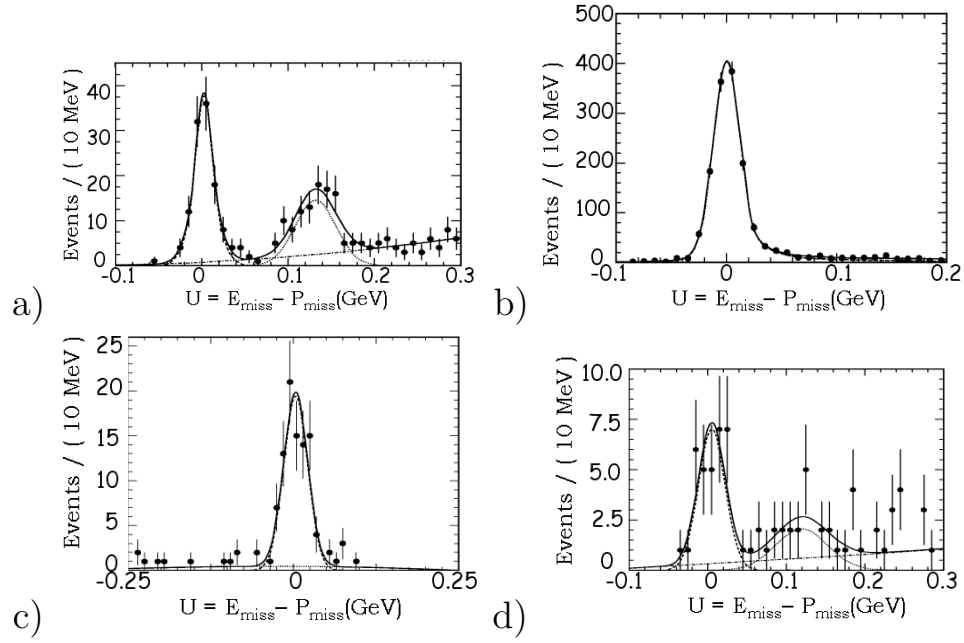
Figure 2: *Distributions of the variable $U \equiv E_{\mathrm{miss}} - P_{\mathrm{miss}}$ for D^0 meson decays to a) $\pi^- e^+ \nu$, b) $K^- e^+ \nu$, c) $K^{*-} e^+ \nu$, $(K^{*-} \to K^- \pi^0)$, d) $\rho^- e^+ \nu$.*

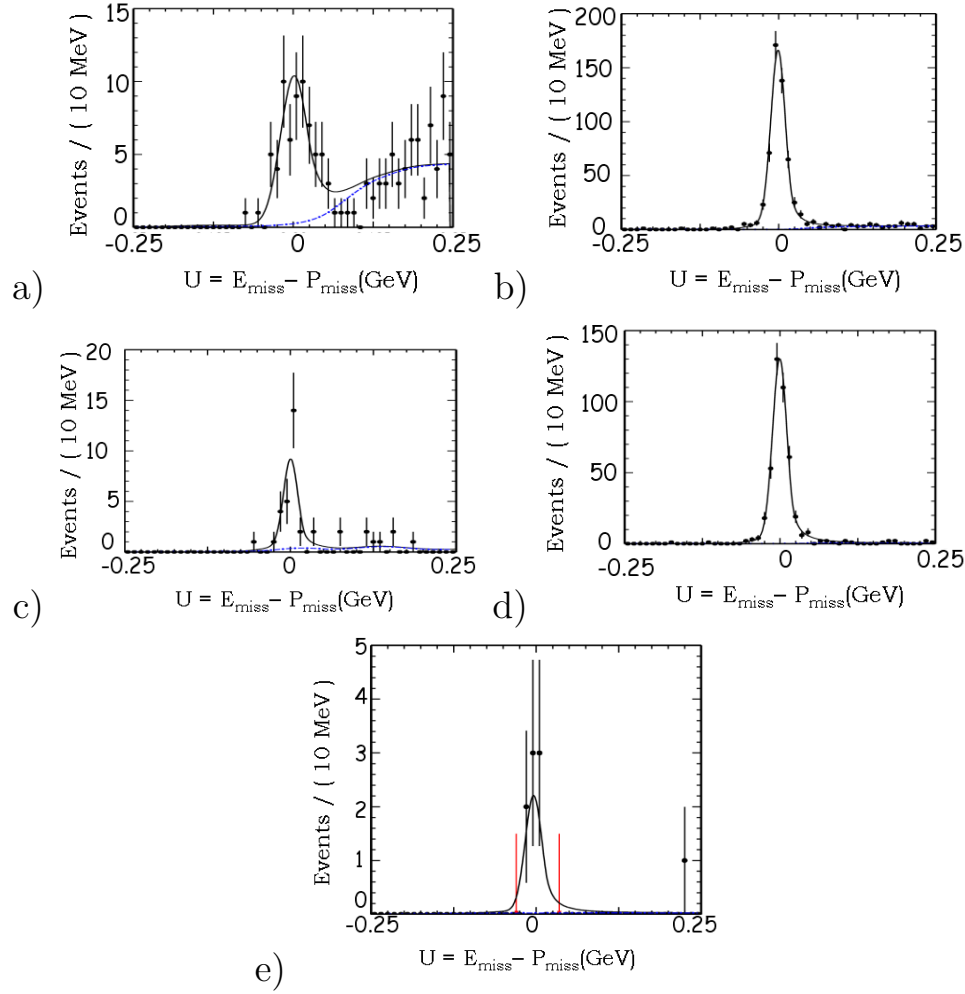Figure 3: *Distributions of the variable $U \equiv E_{\mathrm{miss}} - P_{\mathrm{miss}}$ for D^+ meson decays to a) $\pi^0 e^+ \nu$, b) $\overline{K^0} e^+ \nu$, c) $\rho^0 e^+ \nu$, d) $K^{*0} e^+ \nu$ ($K^{*0} \to K^- \pi^+$), e) $\omega e^+ \nu$.*

channels, respectively. The corresponding statistical $\oplus$ systematic uncertainties for the present best measurements are $\sim 0.3\%$ and $\sim 1.9\%$ for these channels.

5   D Meson Absolute Hadronic Branching Fractions and $D\overline{D}$ Production Cross Sections

Using samples of single and double D tagged events, absolute branching fractions of several hadronic D decay modes are determined independent of the integrated luminosity, which would typically add a large uncertainty to the measurement. This technique is similar to that used by the Mark III collaboration [4] [5]. The number of single D tagged events in a given decay mode i is given by

$$N_i = N_{D\overline{D}}\mathcal{B}_i\varepsilon_i \tag{3}$$

and the number of double tagged events with decays to modes i and j is given by

$$N_{ij} = N_{D\overline{D}}\mathcal{B}_i\mathcal{B}_j\varepsilon_{ij}. \tag{4}$$

Equations 3 and 4 can be combined to give the number of $D\overline{D}$ pairs produced and the branching fraction of each mode i:

$$N_{D\overline{D}} = \frac{N_i N_j}{N_{ij}}\frac{\varepsilon_{ij}}{\varepsilon_i\varepsilon_j} \tag{5}$$

and

$$\mathcal{B}_i = \frac{N_i j}{N_j}\frac{\varepsilon_j}{\varepsilon_{ij}}. \tag{6}$$

In practice, a simultaneous fit to the neutral modes $D^0 \to K^-\pi^+$, $D^0 \to K^-\pi^+\pi^0$, and $D^0 \to K^-\pi^+\pi^+\pi^-$ and charged modes $D^+ \to K^-\pi^+\pi^+$ and $D^+ \to K_S^0\pi^+$ is performed to extract the branching fractions and number of $D\overline{D}$. All statistical and systematic correlations between modes are taken into account in the fit. The fit is of good quality with $\chi^2/N_{\rm d.o.f} = 9.0/16$ and a confidence level of 91.4%.

The efficiencies are determined from a combination of data and Monte Carlo. The denominator of the efficiency calculation may be determined using missing mass to select events in data and Monte Carlo. The effects of final state radiation are included in this analysis.

The single and double D tagged yields are determined using the variables ΔE and M_{bc}, defined in Eqs. (2) and (1), respectively. Approximately 2500 double tagged neutral D mesons and 500 double tagged charged D mesons are reconstructed.

Table 2 sums up the branching fractions and cross sections determined from this preliminary analysis. The statistical uncertainties on the neutral modes are of order 2.0% and of order 4.5% for charged modes.

Table 2: *Absolute branching fractions and ratios of branching fractions of hadronic decays and $D\overline{D}$ production cross sections. All results are preliminary.*

Quantity	CLEO-c Measurement
$\sigma(e^+e^- \to D^0\overline{D^0})$	$3.47 \pm 0.07 \pm 0.15$ nb
$\sigma(e^+e^- \to D^+D^-)$	$2.59 \pm 0.11 \pm 0.11$ nb
$\sigma(e^+e^- \to D\overline{D})$	$6.06 \pm 0.13 \pm 0.22$ nb
$N_{D^+D^-}/N_{D^0\overline{D^0}}$	$0.75 \pm 0.04 \pm 0.02$
$N_{D^0\overline{D^0}}$	$(1.98 \pm 0.04 \pm 0.03) \times 10^5$
$\mathcal{B}(D^0 \to K^-\pi^+)$	$0.0392 \pm 0.0008 \pm 0.0023$
$\mathcal{B}(D^0 \to K^-\pi^+\pi^0)$	$0.143 \pm 0.003 \pm 0.010$
$\mathcal{B}(D^0 \to K^-\pi^+\pi^+\pi^-)$	$0.081 \pm 0.002 \pm 0.009$
$N_{D^+D^-}$	$(1.48 \pm 0.06 \pm 0.04) \times 10^5$
$\mathcal{B}(D^+ \to K^-\pi^+\pi^+)$	$0.098 \pm 0.004 \pm 0.008$
$\mathcal{B}(D^+ \to K^0_S\pi^+)$	$0.0161 \pm 0.0008 \pm 0.0015$
$\mathcal{B}(D^0 \to K^-\pi^+\pi^0)/\mathcal{B}(D^0 \to K^-\pi^+)$	$3.64 \pm 0.05 \pm 0.17$
$\mathcal{B}(D^0 \to K^-\pi^+\pi^+\pi^-)/\mathcal{B}(D^0 \to K^-\pi^+)$	$2.05 \pm 0.03 \pm 0.14$
$\mathcal{B}(D^+ \to K^0_S\pi^+)/\mathcal{B}(D^+ \to K^-\pi^+\pi^+)$	$0.164 \pm 0.004 \pm 0.006$

The uncertainties in the charged track efficiencies used in this preliminary analysis will be reduced by about a factor of four in the final analysis of this preliminary data set. Improvements to the π^0 and K^0_S efficiencies are also nearly complete. Four more charged D modes are presently being added and will improve the statistics in those modes by about a factor of three. These measurements will impact the determination of $|V_{cb}|$ by the B factories using $B \to D^*\ell\nu$.

6 Conclusions

CLEO-c is producing results that will have a large impact on electroweak physics. These measurements are essential for the B factories and the Tevatron experiments to realize their full potential on many measurements. Using only a small preliminary sample corresponding to an integrated luminosity of 60 pb^{-1} many of these measurements are already the most significant. A considerably larger sample is presently being collected at the $\psi(3770)$. The CLEO-c collaboration also plans to study D_s decays in collisions above $D_s\overline{D_s}$ threshold and study radiative J/ψ decays.

7 Acknowledgments

References

1. M. Kobayashi and T. Maskawa, Prog. Theor. Phys. **49**, 652 (1973).

2. CLEO Collaboration, G. Bonvicini *et al*, Phys. Rev. D **70**, 112004 (2004).

3. Particle Data Group, S. Eidelman *et al*, Phys. Lett. B **592**, 1 (2004).

4. Mark III Collaboration, R. M. Baltrusaitis *et al*, Phys. Rev. Lett. **56**, 2140, (1986).

5. Mark III Collaboration, J. Adler *et al*, Phys. Rev. Lett. **60**, 89, (1988).